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RISK OF HIGH PM10 CONCENTRATIONS IN THE ŻYWIEC BASIN DEPENDING ON SYNOPTIC SITUATION

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Abstract

This analysis was performed for the Żywiec Basin area, located in southern Poland. The topography of the Żywiec Basin is an eminently favourable factor for the stagnation of cool air in the basins and the formation of the so-called "cold stagnation areas", as well as the occurrence of inversion layers inhibiting air mixing. In addition, in the Żywiec Basin, the reservoir has a significant influence on the formation of weather conditions. It favours more frequent formation of local fogs and mists.

The study focused on the heating season (6 months) from 2016 to 2021. The analysis covered winter seasons at the turn of the year starting from 1 October and ending on 31 March. During this period, for all heating seasons analysed, the average PM10 concentration was 58 μg/m^3. The 2016/2017 heating season proved to be the worst season in aerosanitary terms, with average concentrations equalling to 78.4 μg/m^3. Extreme levels of daily concentrations during those seasons were recorded in 2016/2017 (349.0 μg/m^3) and 2017/2018 (476.2 μg/m^3). This represented 700–900% of the limit value for PM10 concentrations. The frequency of exceedances of the daily limit value D_{24} for PM10 was high during the heating season, ranging from 83 to 91 days, which represented almost half (46.7%) of the entire season.

The next stage of the analysis comprised the evaluation of the levels of daily concentrations (D_{24}) against the background of the baric situation shaping the weather on a given day. The study juxtaposed the daily concentrations of PM10 in Żywiec with the daily baric situation in the upper Vistula river basin. The anticyclonic situation contributed to an increase in PM10 immission concentrations in all heating seasons from 2016 to 2021. In all analysed months of the heating seasons, differences in the average monthly PM10 concentration depending on the baric situation can be noticed, and the higher the concentration level, the greater this difference is. Similarly, the number of days with exceedances of D_{24} standard for PM10 was several times higher in the period when there was an anticyclone situation. The analysis of the type of air masses showed that the polar continental air masses were accompanied by the worst aerosanitary condition.

Keywords: particulate matter, PM10, temperature inversion, low emission

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1. Introduction

The primary solid air pollutants released during the combustion of solid fuels include PM-ash, soot and fly ash. They can be divided into falling (sedimentable) particulate matter with relatively large grain diameters and suspended particulate matter – light, fine and ultrafine (Pałasz, 2016).

Suspended particulate matter is a composition of solid and liquid particles suspended in atmospheric air, consisting of a mixture of organic and inorganic substances. Suspended particulates vary in origin, composition and size, i.e. aerodynamic diameter.

There are four fractions of particle matter:
- TSP (Total Suspended Particulates),
- PM10 – inhalable particles with a diameter of less than 10 µm,
- PM2.5 – respirable particles with a diameter of less than 2.5 µm,
- PM0.1 – particles with a diameter of less than 0.1 µm (Rogala, Hajok, Marchwińska-Wyrwał, 2015).

PM10 suspended particulate matter is hazardous to human health due to the fact that it has a large adsorption surface area, trapping harmful substances such as persistent organic pollutants (POPs). In addition, suspended particulates have the ability to move, i.e. migrate over long distances. Suspended particulate matter floats for up to several days in the air and then falls to the ground surface from where it migrates from the soil to surface water and to edible plants, and then enters the human body with food. The main component of suspended particulate matter is carbon, in addition to which there are metal compounds, including arsenic, nickel, cadmium, lead, chromium, mercury, aluminium, iron and titanium. PM10 may also contain asbestos and polycyclic aromatic hydrocarbons (PAHs), in particular benzo(a)pyrene (Rogala, Hajok, Marchwińska-Wyrwał, 2015).

Air pollutants have a particularly adverse effect on human health. Poor air quality worsens living and leisure conditions for people residing in urban areas. The impact of harmful substances contributes to an increase in illnesses in the population of large cities and can cause human deaths (Sówka et al., 2016). Atmospheric dust pollution, due to its transboundary effects, causes the contamination of large areas and poses a threat to human health (Kowalska, Kocot, 2016; Krzeszowiak, Pawlas, 2018).

In Poland, air quality in many population centres is among the worst in the entire European Union. Particular attention is drawn to suspended particulate matter (PM2.5 and PM10), aromatic hydrocarbons, dioxins, furans and heavy metals. The World Health Organisation's reports show that of the 50 most polluted cities in the European Union, as many as 33 are located in Poland and 7 are in the top 10. Indirectly, ca. 45,000 people die each year in Poland due to low emission (Cholewiński, Kamiński, Pospolita, 2016; Góra, 2020; EEA, 2018).

The pollution problem increases significantly during the heating season owing to the widespread use of individual boilers and solid fuel furnaces in Polish homes.

In addition, meteorological conditions also have an impact – especially the lack of precipitation and wind increases the concentration of harmful compounds in the air (Kostrz, Satora, 2017; Wierzbińska, Szczepaniak, 2021).

High PM10 concentrations are associated with air temperature, wind speed, direction of air masses advection and the occurrence of precipitation (Czernecki et al., 2016; Rawicki, 2014; Jędruszkiewicz, Piotrowski, Pietras, 2016; Jędruszkiewicz, Czernecki, Marosz, 2017). In high-pressure situations, the lowering of ground-level mixing layer leads to higher particle concentrations. In contrast, lower concentrations of PM10 are recorded during precipitation events. High atmospheric humidity favours the aggregation of dust particles and faster deposition (Ćwiek, Majewski, 2015; Oleniacz et al., 2014).

Authors of many studies have also attempted to determine the impact of meteorological conditions on pollutant concentrations (Kalbaczyk, R., Kalbarczyk, E., Raszka, 2018; Czarnecka, Nidzgorska-Lencewicz, 2017; Majewski et al., 2018; Dacewicz et al., 2019; Palarz, Celiński-Mysław, 2017a; Palarz, Celiński-Mysław, 2017b; Azizi Ghasem, AliAkbar Shamsipour, Morteza Miri & Taher Safarrad, 2012; Yaping Shao, Martina Klose, Karl-Heinz Wyrwoll, 2013; Nasim Hossein Hamzeh, Sara Karami, Christian Opp, Ebrahim Fattahi & Vuillaume Jean-François, 2021; Soodabeh Namdari, Neamat Karimi, Armin Sorooshian, GholamHasan Mohammadi, Saviz Sehatkashani, 2018; Sara Karami, Nasim Hossein Hamzeh, Khan Alam, Faezeh Noori, Abbas Ranjbar Saadat Abadi, 2021).

2. Methodology

The analysis was performed for the Żywiec Basin area located in southern Poland (Figure 1). The topography of the Żywiec Basin is an eminently conducive factor to the stagnation of cool air in the basins and the formation of the so-called "cold-air basins" as well as to the occurrence of inversion layers that inhibit air mixing. What is more, in the Żywiec Basin the reservoir has a substantial influence on weather conditions. It is conducive to more frequent formation of local fogs and mists (Palarz, Celiński-Mysław, 2017a; Palarz, Celiński-Mysław, 2017b; Wierzbińska, Kozak, 2023).

The Żywiec Basin is a large, triangular-shaped, mid-mountain basin located in the Western Beskids, the centre of which lies in the area of the confluence with the Soła River of its two large tributaries: the right-bank Koszarawa and the left-bank Żylica.

According to Jerzy Kondracki's scientific regionalisation of Poland, the Żywiec Basin is bordered to the west by the Silesian Beskids, to the north by the Silesian Foothills (linked to it by the Wilkowicka Gate) and the Little Beskids, and to the southeast and south by the Maków Beskids and the Żywiec Beskids. Located at an altitude of 340–500 m above sea level, the valley bottom has a length from west to east of about 20 km, a width from south to north of about 15 km and an area of about 320 km^2.

Figure 1. Location of the study area

In the study use was made of materials from the data bank of the measurement station of the Chief Inspectorate of Environmental Protection in the town of Żywiec (Coordinates: WGS84 x: 49.671602 y: 19.234446) at an altitude of 368 m above sea level. The utilised synoptic situation comes from the computer collection of Prof. T. Niedźwiedz from the Department of Climatology at the University of Silesia, as a calendar of atmospheric circulation types for southern Poland, and digital materials made available by the author until 2021 (Niedźwiedź, 2017).

Coding of circulation types in a set - 21 types

Anticyclonic types (1–10):

1 – Na	—	North (direction of air masses advection, geostrophic wind),
2 – NEa	—	North–East
3 – Ea	—	East
4 – SEa	—	South–East
5 – Sa	—	South
6 – SWa	—	South–West
7 – Wa	—	West
8 – NW	—	North–West
9 – Ca	—	central anticyclone situation (high center)
10 – Ka	—	anticyclonic wedge or ridge of high pressure.

Cyclonic types (11–20):

11 – Nc	—	North
12 – NEc	—	North–East

13 – Ec — East
14 – SEc — South–East
15 – Sc — South
16 – SWc — South–West
17 – Wc — West
18 – NWc — North–West
19 – Cc — central cyclonic, center of low
20 – Bc — through of low pressure (different directions of air flow and frontal system in the axis of through)
21 – x — unclassified situations or pressure col.

3. Results and discussion

The concentrations of PM10 as an air quality indicator connected with solid fuel combustion and partly with traffic emissions are mainly associated with winter – the heating season. This is when daily D_{24} standards of PM10 immission concentration are exceeded. Consequently, the focus was on the heating season (6 months) in the years 2016 to 2021. The analysis covered the winter seasons at the turn of the year starting from 1 October and ending on 31 March. During this period, for all heating seasons analysed, the average PM10 concentration was found to be 58 μg/m^3. The 2016/2017 heating season proved to be the worst season in aerosanitary terms, with average concentrations of 78.4 μg/m^3. Extreme levels of daily concentrations during those seasons were recorded in 2016/2017 (349.0 μg/m^3) and 2017/2018 (476.2 μg/m^3) (Table 1). This represented 700-900% of the limit value for PM10 concentrations (Journal of Laws of 2012, item 1031).

Table 1. Average and extreme concentrations of PM10 in the heating seasons from 2016 to 2021

Values	2016/2017	2017/2018	2018/2019	2019/2020	2020/2021	Average
Average (μg/m^3)	78.4	64.4	52.9	41.7	52.8	58.0
Max (μg/m^3)	349.0	476.2	234.0	145.4	241.2	476.2
Min (μg/m^3)	11.0	8.2	9.1	8.4	6.5	6.5
SD (μg/m^3)	72.8	56.6	37.6	26.6	35.5	50.2

During months of the cold season when homes need to be heated, no significant regularity is evident outside of 2016/2017, and even in 2017/2018 the highest monthly average (93.9 μg/m^3) PM10 concentrations were recorded towards the end of the heating season (Figure 2).

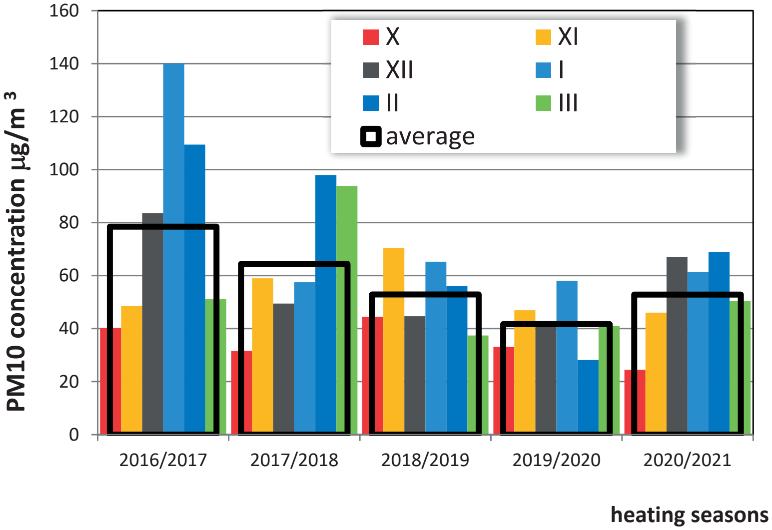


Figure 2. Monthly average concentrations of PM10 against averages over the heating seasons in the 2016-2021 study period

The frequency of exceedances of the daily limit value D_{24} for PM10 is high during the heating season, ranging from 83 to 91 days, which is almost half (46.7 %) of the entire season (Table 2). Monthly regularity is not apparent either, as 22 days with exceedances of the standard were recorded in October 2018/19, January 2016/17 as well as February 2017/18. Concentration levels are therefore influenced by synoptic conditions, i.e. the current weather in this part of Poland.

Table 2. Frequency (days) of exceedances of D_{24} standard for PM10 in Żywiec in individual months and heating seasons from 2016 to 2021

Heating period/ months	Oct	Nov	Dec	Jan	Feb	Mar	Total days
2016/2017	10	9	17	22	18	15	**91**
2017/2018	5	18	11	14	22	19	89
2018/2019	11	22	9	13	18	10	83
2019/2020	6	11	10	15	4	11	57
2020/2021	0	12	19	17	18	17	83

The next stage of the analysis comprised the evaluation of daily concentration levels (D_{24}) against the baric situation shaping the weather on a given day. An anticyclonic situation (ridge of high pressure) is conducive to air subsidence and thus limits the dispersion of waste gases in the atmosphere, resulting in the concentration of PM10 in the lower layers of the atmosphere. Such a situation favours the occurrence of smog phenomena and as a consequence exceedances of limit values. On the other hand, a cyclonic situation (through low pressure) favours convection (air uplift), which allows the dispersion of emitted waste gases in the atmospheric air (Figure 3).

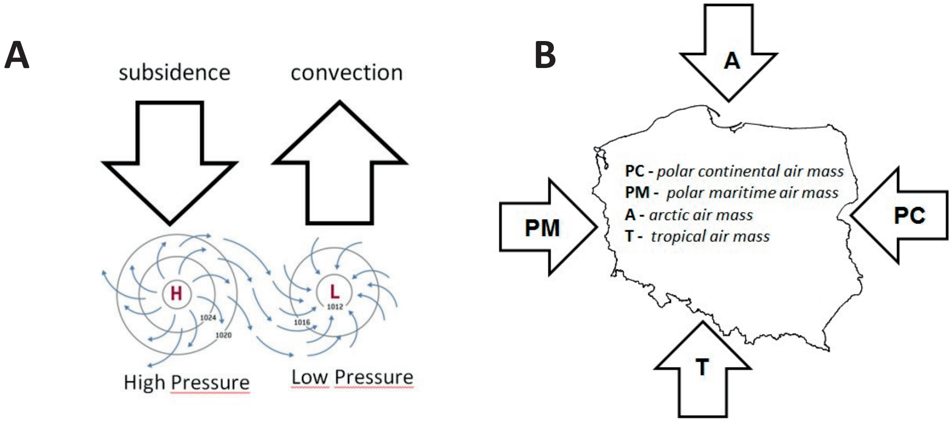


Figure 3. Diagram of anticyclonic system - ridge of high pressure (A) and cyclonic system - through low pressure in the northern hemisphere with directions of air masses advection over Poland (B)

This study compares the daily concentrations of PM10 in Żywiec with the daily baric situation from the upper Vistula river basin. The anticyclonic situation contributes to an increase in PM10 immission concentrations in all heating seasons from 2016 to 2021 (Figure 4).

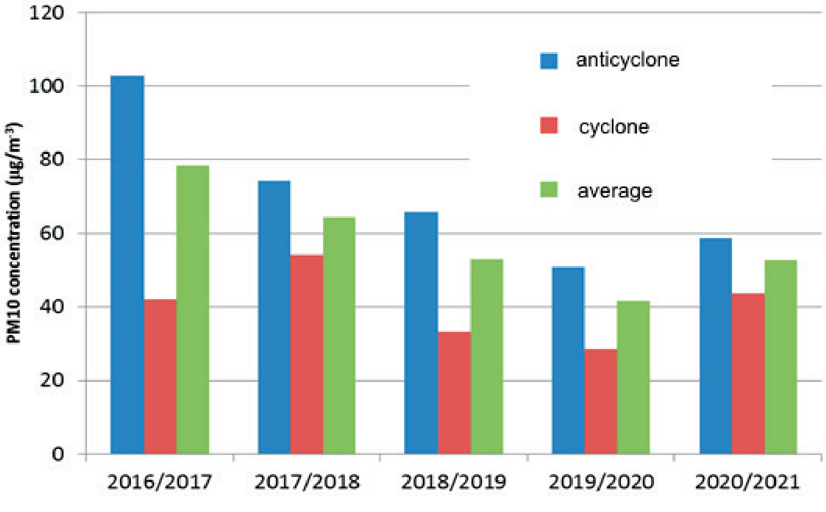


Figure 4. Average concentrations of PM10 in cyclonic and anticyclonic baric situations in the individual heating seasons from 1016 to 2021

In all the analysed months of the heating periods, differences in the monthly average PM10 concentration can be seen depending on the baric situation, and the higher the concentration level, the greater this difference is, such as in December and January of the 2016/17 season (Table 3).

Table 3. Average concentrations of PM10 in anticyclonic (a) and cyclonic (c) baric situations during the heating periods from 2016 to 2021

Season	**Oct**		**Nov**		**Dec**		**Jan**		**Feb**		**Mar**	
	a	**c**	**a**	**c**	**a**	**c**	**a**	**c**	**a**	**c**	**a**	**c**
2016/2017	48.3	34.3	60.9	37.7	101.2	23.0	171.3	32.7	131.5	80.0	60.1	38.6
2017/2018	39.8	21.7	72.7	41.0	64.6	35.2	66.6	50.0	115.8	89.9	125.7	76.4
2018/2019	52.4	30.1	74.6	31.8	61.5	21.4	110.0	46.9	61.2	40.3	52.1	23.6
2019/2020	40.1	16.1	64.4	35.3	46.1	37.9	65.4	19.8	35.5	22.2	49.0	28.1
2020/2021	27.6	21.8	46.4	40.7	85.1	52.2	81.1	49.0	70.2	65.4	55.0	39.0
Average	42.1	25.6	63.0	37.5	74.0	36.2	102.4	44.9	78.2	60.7	63.3	44.2

Similarly, the number of days with exceedances of D_{24} standard for PM10 is several times higher during the period when there is an anticyclonic situation (Figure 5).

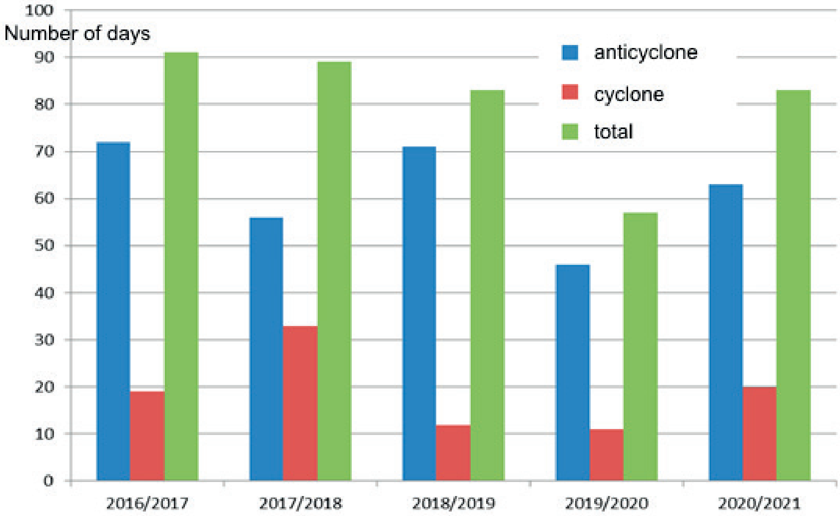


Figure 5. Frequency of exceedances of PM10 standard (D_{24}=50μg/m^3) in the individual heating seasons from 2016 to 2021

This becomes even more evident in the analysis of months when exceedances of the standard occur on days on which the weather is shaped by anticyclonic periods (Table 4). The highest ratio of days with exceedances of the limit value, over the entire study period for the baric situation, was recorded in the month of November (5.1 times more cases for the anticyclonic situation) and the lowest such ratio in the month of March (2.2 times more cases for the anticyclonic situation).

Table 4. Frequency of exceedances of PM10 daily standard (D_{24} =50µg/m^3) in the individual months of the 2016–2021 heating seasons

Season	Oct		Nov		Dec		Jan		Feb		Mar	
	a	c	a	c	a	c	a	c	a	c	a	c
2016/2017	6	4	6	3	17	0	21	1	12	6	10	5
2017/2018	4	1	13	5	8	3	7	7	14	8	10	9
2018/2019	10	1	21	1	9	0	6	7	16	2	9	1
2019/2020	6	0	8	3	6	4	15	0	3	1	8	3
2020/2021	0	0	12	0	13	6	10	7	15	3	13	4
Total	26	6	60	12	53	13	59	22	60	20	50	22

In the analysis of PM10 concentrations taking into account the synoptic situation – the advection of air masses shaping the weather in Poland (Figure 3B) – a comparison is made of the average concentrations and the number of days when the standard was exceeded with the air masses arriving in Poland. Arctic and polar continental air masses bring cooling of the air in the winter period, which translates into increased heating of houses and intensified waste gases causing elevated concentrations of PM10 in the air (in immission). However, simply juxtaposing and averaging PM10 values with the occurrence of a given air mass can bias such an analysis. For example, an arctic air mass may occur in the warmer months of the heating season, such as October or March, resulting in lower air temperatures to a lesser extent than a continental air mass in the months of December, January and February, bringing very cold air and in this way influencing the response associated with increased fuel combustion and thus increased amount of waste gases (Table 5).

Table 5. Average concentrations of PM10 for occurring air masses *(A – arctic air mass, PC – polar air mass, PM – polar maritime air mass, T – tropical air mass, DAM – different air masses*) in southern Poland in the heating periods from 2016 to 2021

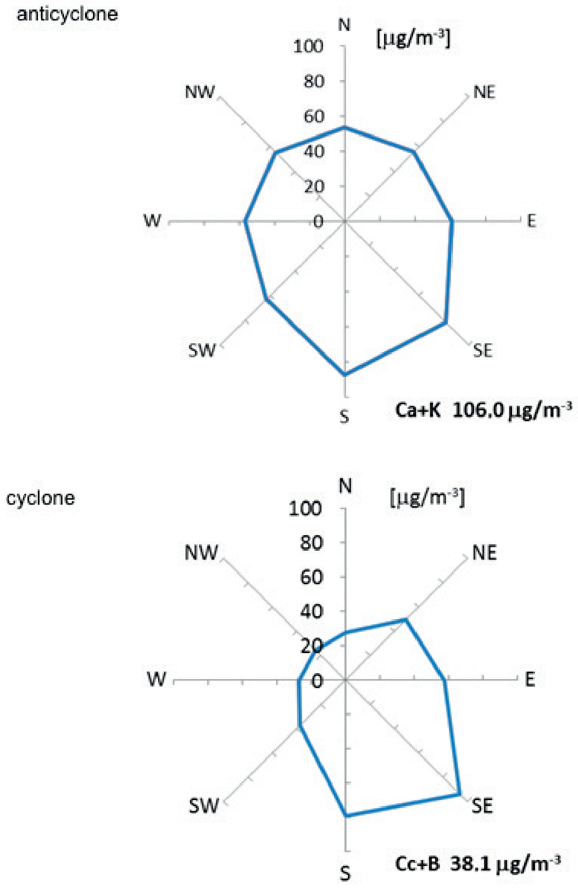
Season	A	PC	PM	T	DAM
2016/2017	71.8	136.6	58.4		33.0
2017/2018	48.7	100.3	47.8		45.6
2018/2019	36.6	86.6	39.1	22.9	40.4
2019/2020	45.8	69.1	40.7	39.2	32.9
2020/2021	48.0	80.8	45.5		40.0
Average	**52.4**	**107.8**	**48.4**	**22.9**	**39.7**

The extreme values of PM10 concentrations as well as the frequency of exceeding the standard for the entire study area are presented for the individual directions of air masses advection (Table 6).

Table 6. Extreme values of PM10 concentrations (μg/m^{-3}) and exceedances of PM10 D_{24} standard for each type of circulation (2016–2021)

Type	Maximum	Minimum	Days PM10> D_{24}
Na	137.4	17.3	12
NEa	220.5	10.6	14
Ea	207.1	20.4	17
SEa	195.5	19.2	26
Sa	296.6	29.3	22
SWa	264.6	9.3	50
Wa	244.1	9.6	42
NWa	277.6	9.0	38
Ca	476.2	40.2	50
Ka	349.0	25.7	21
Nc	52.4	12.5	1
NEc	134.7	11.4	6
Ec	155.0	11.0	5
SEc	243.8	29.0	14
Sc	226.1	8.8	8
SWc	179.0	8.2	14
Wc	87.1	8.4	9
NWc	102.9	10.2	2
Cc	74.8	6.5	2
Bc	170.3	7.1	26
DAM	165.4	36.3	24

The radar distribution of PM10 concentrations has been developed for the main directions of air masses advection, taking into account cyclonic and anticyclonic situations (Figure 6). In both cases, the highest concentrations were recorded in the southern (78.7–87.8 μg/m^3) and south-eastern (81.9–93.8 μg/m^3) directions. On the other hand, as confirmation of previous analyses of PM10 concentrations with the baric situation, the highest concentrations occurred in the central high pressure system (106.0 μg/m^3).



Legend: Ca+K central anticyclone + anticyclonic wedge or ridge of high pressure
Cc+B central cyclonic + trough of low pressure

Figure 6. Average PM10 concentrations [μg/m^{-3}] in the heating periods from 2016 to 2021 for cyclonic and anticyclonic types

4. Conclusions

1. In the Żywiec Basin, the limit value for daily (D_{24}) concentration of PM10 is high and was exceeded on average during 83–91 days in the individual heating seasons from 2016 to 2021 (the limit value for frequency of exceedances is 35 days per year (Polish Journal of Laws/Dz.U. 2012, item 1031).
2. The highest PM10 concentrations exceeding the limit value were observed in anticyclonic non-directional conditions (Ca) and during air masses advection from southern directions (SE, S and SW). During cyclonic weather, high concentrations exceeding the limit values during the heating period occurred sporadically.

3. An analysis of the type of air masses showed that the polar continental air masses were accompanied by the worst aerosanitary condition.
4. Identification of the synoptic situation may be one of the elements in the forecast of smog alerts in the Żywiec Basin region.

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Nauka

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RYZYKO WYSOKICH STĘŻEŃ PYŁU PM10 W KOTLINIE ŻYWIECKIEJ W ZALEŻNOŚCI OD WARUNKÓW SYNOPTYCZNYCH

Abstrakt

Analizę wykonano dla obszaru Kotliny Żywieckiej, położonej w południowej Polsce. Topografia Kotliny Żywieckiej jest czynnikiem wybitnie sprzyjającym stagnacji chłodnego powietrza w kotlinach i tworzeniu się tzw. „zastoisk chłodu", a także występowaniu warstw inwersyjnych hamujących mieszanie powietrza. Ponadto, w Kotlinie Żywieckiej istotny wpływ na kształtowanie warunków pogodowych wywiera zbiornik retencyjny. Sprzyja on częstszemu tworzeniu się lokalnych mgieł i zamgleń.

W pracy skoncentrowano się na okresie grzewczym (6 miesięcy) w latach 2016-2021. Analizą objęto sezony zimowe na przełomie roku począwszy od 1 października, kończąc na 31 marca. W tym okresie, dla wszystkich analizowanych sezonów grzewczych średnie stężenie PM10 wyniosło 58 μg/m^3. Sezon grzewczy 2016/2017 okazał się najgorszym sezonem pod względem aerosanitarnym, ze średnim stężeniem 78,4 μg/m^{3,} Ekstremalne poziomy stężeń dobowych w sezonach odnotowano w sezonach 2016/2017 (349,0 μg/m^3) oraz 2017/2018 (476,2 μg/m^3). Stanowiło to 700–900% wartości dopuszczalnej dla stężenia PM10. Częstość przekroczeń dobowej wartości dopuszczalnej D_{24} dla pyłu zawieszonego PM10 była w sezonie grzewczym wysoka i wahała się od 83-91 dni, co stanowiło prawie połowę (46,7 %) całego sezonu.

Kolejnym etapem analizy była ocena poziomów stężeń dobowych (D_{24}) na tle sytuacji barycznej kształtującej pogodę w danym dniu. W pracy zestawiono dobowe stężenia pyłu zawieszonego PM10 w Żywcu z dobową sytuacją baryczną z dorzecza górnej Wisły. Sytuacja antycyklonalna przyczyniała się do zwiększenia stężenia pyłu PM10 w immisji we wszystkich sezonach grzewczych 2016-2021. We wszystkich analizowanych miesiącach okresów grzewczych dostrzec można różnice w średnim miesięcznym stężeniu PM10 w zależności od sytuacji barycznej, a im wyższy poziom stężenia tym ta różnica jest większa. Podobnie ilość dni z przekroczeniem normy D_{24} dla pyłu zawieszonego PM10 była wielokrotnie wyższa w okresie, kiedy występowała sytuacja antycyklonalna. Analiza typu mas powietrza wykazała że najgorszy stan aerosanitarny towarzyszył masom powietrza polarno-kontynentalnego.

Słowa kluczowe: pył zawieszony, PM10, inwersja temperatury, niska emisja